



Examining Whether Economic Policy Uncertainty Has A Significant Impact on Compensation for Alteration—An Analysis Based on The Granger Causality Test

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Abstract

The Spatial Planning Act of Taiwan was implemented on May 1, 2016. To protect the legal rights of landholders, the Ministry of the Interior stipulated Measures for Compensating Loss Incurred during The Implementation of Spatial Planning in accordance with Article 32, Paragraph 3 of the Spatial Planning Act. Compensation is available for relocation or for alteration, where alteration refers to compensation for losses incurred when constructible land is made nonconstructible by a special municipality or county (city) and the land cannot be built on. It therefore includes compensation for the value of the right to develop the land.

This study is based on the real options valuation model, assuming that the compensation for the alteration of privately-owned constructible land follows a geometric Brownian motion. It proposes a related valuation model, conducts sensitivity analysis, and further employs the Granger causality test to examine whether economic policy uncertainty has a significant impact on compensation for alteration.

This study also provides decision-making recommendations on the appropriate timing for applying for compensation for alteration, along with corresponding methods for assessing trends in average price volatility (σ_s). Taking Taichung City as an example, there is no causal relationship between the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU). Therefore, when calculating the option premium (OP), changes in the Taiwan EPU index alone cannot be used as the basis for determining the future trend of σ_s . In such cases, the future trend of σ_s can be assessed by incorporating “economic structural factors” into the analysis of land price determinants.

The valuation model developed in this research provides an objective and comprehensive framework for the compensation for the alteration of privately-owned constructible land, and the findings can serve as a reference for landowners who have suffered losses when applying for compensation for alteration.

Keywords: Compensation for alteration, Real option valuation model, Economic policy uncertainty, Granger causality test, Geometric Brownian motion

1. Introduction

The Spatial Planning Act, formulated by the Executive Yuan, was in effect on May 1, 2016. According to Article 45 of the Act, the central competent authority was to announce the implementation of the national spatial plan within two years starting from the date that the Act came into effect. The Ministry of the Interior was to promulgate and implement a national spatial plan in accordance with previous regulations and submit it to the Executive Yuan for approval. The plan was promulgated and

implemented on April 30, 2018. The Spatial Planning Act was revised by the president on April 21, 2020, and January 20, 2026, respectively. The development periods for special municipality and county (city) spatial plans and functional zone maps were extended to April 30, 2021, and 2031, respectively (Shieh & Su, 2023) ^[48].

To protect the rights of landholders, the Ministry of the Interior established the Measures for Compensating Loss Incurred during The Implementation of Spatial Planning on the basis of Article 32, Paragraph 3 of the Spatial Planning Act. The document follows the scope of compensation specified in the Spatial Planning Act and divides it into two categories, namely, compensation for relocation or alteration. Compensation for alteration refers to compensation for losses sustained when existing constructible land is "altered" to be nonconstructible according to the spatial planning of the special municipality or county (city). It also refers to compensation for the value of the right to develop the land (reflected in the difference in unit land price before and after the implementation of the spatial plan), and land is not expropriated. Therefore, the calculation method is not identical to that for expropriation (Shieh & Su, 2023) ^[48].

Real estate is immobile and inflexible, which reduce uncertainty in its use. In the past, the net present value (NPV) method was generally used for land investment and development analysis. Dixit & Pindyck (1994) ^[13] noted that the conventional passive NPV method is used to appraise land value and usually assumes that the investment plan is developed immediately and reversible. These are contrary to the characteristics of real estate investment and development; that is, ignoring the opportunities and flexibility generated by the uncertainty of asset value can readily lead to misappraisal of the value of investment plans. Specifically, the inclusion of future uncertainty in the appraisal is the main difference between option valuation models and conventional valuation models. McDonald and Siegel (1986) discussed the effects of future cash flow and investment cost uncertainty on option value and timing in investment projects, assuming that both earnings and cost conform to the stochastic process of geometric Brownian motion (Shieh & Su, 2023; Peng *et al.*, 2011) ^[48, 44].

Titman (1985) ^[53] applied real options theories to land development and noted that real options affect the land development decisions of landowners. Real options theories state that the uncertainty of the future situation is the source of real option value. As the uncertainty increases, the

opportunity for land development is delayed and the value of undeveloped land increases (Shieh & Su, 2023; Liu, 2006) ^[48].

Because correct calculation of the compensation for alteration is crucial to whether landowners obtain appropriate compensation, this study is based on the real options valuation model, assuming that the compensation for the alteration of privately-owned constructible land follows a geometric Brownian motion. It proposes a related valuation model. In the model, landowners have complete ownership of and decision-making power over constructible land before receiving compensation for alteration. By using real options theories, private landowners can determine the real options of the model at the decision-making stage.

In addition to conducting sensitivity analysis, this study employs the Granger causality test to examine whether economic policy uncertainty has a significant impact on compensation for alteration. It also provides decision-making recommendations on the appropriate timing for applying for compensation for alteration, along with corresponding methods for assessing trends in average price volatility.

2. Literature review

The right to development refers to the right of landowner to change the mode of use of the land for more intensive use or to engage in construction or development. It is a right created by property law as derived from ownership (Costonis, 1973) ^[11].

Su (2023) and Shieh & Su (2023) ^[52, 48] applied the concept of the right to development originated in the United Kingdom (UK), whereas that of transferable development rights (TDR) originated in the USA. The purchase of development rights (PDR) evolved into the TDR due to financial budget issues.

The right to development is a right that is created by society and governed by law; and has economic value. According to the planning viewpoint, the right to development should be restricted by land use control, and development should be pursued without affecting the private ownership of land or land use planning. It limits the spread of social externalities and protects private and public ownership (Su, 2023; Wu, 2000) ^[52, 55].

This study analyzed and compiled literature on the right to development. Domestic and nondomestic literature on PDR calculation are shown in Table 1 and 2, respectively (Su, 2023; Shieh & Su, 2023) ^[52, 48].

Table 1: Summary of Taiwanese literature on PDR calculation

Research topic	Author (Year)	Empirical region or law	Methodology	Results
An Analysis of Compensation for the Restricted Use of Farmland in Water Resource Protection Areas in Germany	Chen (1998)	Germany	Literature review and meta-analysis	The study used legal analyses, case analyses, and characteristics analyses of farmland use restriction and loss compensation in Germany's water resource protection areas as a reference for Taiwan. Taking Baden-Württemberg and North Rhine-Westphalia as examples, loss caused by restrictions on the use of pesticides and fertilizers (which caused decreases in crop yields of farmland) in restricted water resource protection areas was explained and estimated.
A Study on the Implementation of Agricultural Conservation Easement—Based on Administrative Deed	Ling (2005)	Sanxing Township, Yilan County	Literature review and case study	Through analyses of related literature and cases of agricultural easements in the USA, the study identified the practical application of agricultural easements and explained the direction of domestic applications of agricultural land maintenance and management. A simulation of the implementation in Sanxing Township, Yilan County was used to understand the problems that frequently occur when purchasing domestic agricultural easement, such as small-

				scale agricultural land, large number of property owners, and complex attributes. The study explored and explained how agricultural easements in Taiwan should be constructed to address the domestic environmental policy background, and proposed voluntary participation in the negotiation of agricultural easements as the setting mechanism (top-down planning and bottom-up application), and adjusted the agricultural easements operating method in Taiwan.
The research to evaluate the non-market value in Agricultural Easement - A study of I-LAN	Hu (2006)	Yilan County	Literature and empirical analysis	The study discussed the possible macroeconomic benefits of agricultural easement planning and explored its nonmarket value. Subsequently, agricultural easement value was evaluated through nonmarket value evaluation techniques, and Yilan County was selected for empirical study.
Application of the U.S. Agricultural Easement to the Conservation of Agricultural Land Resources in Taiwan	Ling and Chen (2007)	Agricultural land policies of Taiwan	Literature review	With the connotation of restriction on the use of agricultural easement, it led to the conservation of agricultural land control idea, and introduced the planning and practice of this system in the USA as a reference for domestic agricultural land policy.
Study on Feasibility of Transform Value of Rights Model of Land Expropriations by Analyzing Land Value Factors	Lin (2009)	Public real estate bidding in Taichung City	Literature review, analytic hierarchy process, and fuzzy theory	Factors influencing land price were summarized through a literature review. Questionnaires were used to obtain the factors affecting bid price changes and weight ranking, and to discuss the method of replacing money payment with value of rights transformation. It also considered combining with the concept of equivalent exchange in the PDR method and proposed a value of rights ratio transformation model as a strategic approach to the problem of acquiring land for public facilities.
The Study on Charitable Trust - With Analysis of the Conservation Easement	Tung (2012)	Trust law	Literature review and system comparison	By discussing the conservation easement of charitable trusts in the UK and USA, the study compared the differences between conservation easements and real estate easements in Taiwan, and analyzed applying the conservation easement system to the preservation of cultural assets or environmental and ecological conservation through revision of the legal system.
The Institutional Design of Transferable Development Rights for Farmlands in Taiwan	Liu (2012)	TDR for farmlands in Taiwan	Literature review	By analyzing the theoretical basis of the TDR, economy, and actual cases in the USA, the study extended the TDR scope to farmland conservation policies according to the current agricultural situation in Taiwan, and discussed the applicable farmland TDR system and design process from different detailed plans.
Introducing Conservation Easements into Taiwan's Private Land Conservation - Studies of Statutory Covenants of National Trust And Conservation Easements of United States	Kao (2013)	Qionglin Township of Hsinchu County, Natural Valley Environmental Education Base in Hengshan Township, Civil Code, Trust law	Literature review	After reviewing the statutory covenants of the British National Trust and the U.S. conservation easement system, the study proposed legislative suggestions for the conservation easement system in Taiwan.

Source: Compiled by this study

Table 2: Summary of nondomestic literature on PDR calculations

Research topic	Author or institution (Year)	Empirical region	Research results
Evaluating Farmland Preservation through Suffolk County, New York's Purchase of Development Rights Program Comment	Mark R. Rielly Follow (2000)	Suffolk County, New York, USA	The PDR provides a legal and permanent method of land protection. However, the evaluation of farmland conservation efforts in Suffolk County demonstrated that the effectiveness of the PDR program was limited, and it was most successful when performed as part of a larger farmland conservation effort. Although the PDR of farmland can permanently preserve the land, this method is severely restricted by the cost of obtaining these rights. As the program of the Suffolk County recommends, even with all the authorized funds, other preservation methods are still necessary. Therefore, wealthier communities may find PDR program unfeasible. However, it may be worthwhile to purchase permanent protection measures to protect the identity of the community from the threat of sprawl development.
Agricultural Conservation Easements and Appraisals	New York Agricultural Land Trust	New York	The study explained estimation of the value of conservation easements.
Stafford County Purchase of Development Rights (PDR) Program Frequently Asked Questions	Stafford County's PDR Committee (2017)	Stafford County, Virginia, USA	The study explained PDR and related calculation methods.

Purchase of Development Rights Ordinance	Prince William County (2019)	Prince William County, Virginia, USA	The study explained the PDR ordinance in the area.
Whatcom County Agricultural, Forestry, and Ecological Purchase of Development Rights PROGRAM GUIDELINES	Whatcom County (2018)	Whatcom County, Washington, USA	The study explained the guidelines for the Agricultural, Forestry and Ecological PDR Program in Whatcom County.

Source: Compiled by this study

The right to development is generally purchased by government agencies or other organizations (e.g., land trusts) for appropriate purposes. The terms of agreement are legally binding, and the conservation easement is set on the deed of the real property. Participants retain the ownership and other rights of the real property, and can settle, cultivate, inherit, purchase, or transfer the property, and provide undeveloped land as a conservation easement in accordance with the contract. Most easement restrictions limit real estate to only agricultural use, whereas conservation easements generally may be used as farmhouses, employee dormitories, or self-occupied buildings (Su, 2023; Department of Urban Development, Taipei City Government, 2010) ^[52, 31].

In most PDR programs, property development rights are valued by real estate appraisers or local easement appraisal systems. The value of the development right is the price difference between the value of the land under control and the maximum and most appropriate use of the land. The organization or institution that manages the PDR program pays the valuation amount to the real estate owner. For instance, if a farmer owns 100 acres of land, the land is worth US\$10,000 per acre on the market if it is available for residential use. An independent real estate appraiser estimates that the land value at only US\$5,000 per acre if the land remains undeveloped and continues to be used for agricultural purposes. Thus, the current value of the development right is US\$500,000 and the PDR program must pay farmers this price (Su, 2023; Department of Urban Development, Taipei City Government, 2010) ^[52, 31].

According to Shieh & Su (2021) ^[47], real options theory originated in 1977 with the ground-breaking idea of Stewart Myers that Black-Scholes financial option pricing model developed in 1973 can be applied to capital-budgeting, later it was proved by Folta & O'Brien (2004) ^[17] and Borison (2005) ^[3]. Myers (1977) ^[41] originally defined "real options" as: "opportunities to purchase real assets on possibly favourable terms" (Čirjevskis & Tatevosjans, 2015) ^[10].

Refer to Li *et al.* (2014) and this study, Real option valuation model (ROV) has been utilized in a variety of real estate development decision, from planning to operations and from operations to abandonment (Hui *et al.*, 2010) ^[36, 30]. Some studies apply ROV to predict land prices (Grovenstein *et al.*, 2011) ^[22] or rent of soil (Hsieh & Lin, 2016) ^[26], and some scholars utilize ROV to value certain types of real estate development, such as recreational facilities (Leung & Hui, 2002) ^[35], public housing upgrading (Ho *et al.*, 2009) ^[24], office construction (Fu & Jennen, 2009) ^[18] and farm (Stokes, 2012) ^[51].

According to Su (2023); Gerlach & Peng (2005) ^[52, 20], cointegration analysis and an error correction model were used to examine the relationship between bank lending and

housing prices in Hong Kong. The empirical results show that housing prices have a significant impact on the total amount of bank lending in both the long run and the short run. However, the Granger causality analysis indicates that the total amount of bank lending does not Granger-cause housing prices.

According to Su (2023) and Li (2022) ^[52, 37], previous literature examining how economic policy uncertainty is transmitted and how it affects the real estate market often employs the Granger causality test for analysis. El-Montasser *et al.*, (2016) ^[14] used the Granger causality test to investigate the causal relationship between real housing prices and economic policy uncertainty in seven developed countries—Canada, France, Germany, Italy, Spain, the United Kingdom, and the United States. Their empirical results indicate a bidirectional causal relationship between real housing prices and economic policy uncertainty.

In addition, Bouri, Gupta, Kyei, 與 Shivambu (2021) ^[4] employed the quantile Granger causality test to examine whether returns and volatility in the U.S. real estate market are affected by economic policy uncertainty. The empirical findings show that the economic policy uncertainty index does indeed influence housing returns and volatility in the United States, exhibiting a unidirectional causal relationship. According to Su (2023) and Que (2011), the Granger causality model is a type of time series Vector Autoregression (VAR). This testing model is based on the perspective of prediction, examining the "correlation" between the current value of a variable and the past values of other variables, rather than representing true causality in macroeconomic theory.

The definition of Granger causality is as follows: suppose there are two variables, X and Y. When predicting Y, in addition to the past lagged values of Y itself, if incorporating past information from variable X reduces the prediction error of Y and improves its predictive accuracy, then X is said to "Granger-cause" Y. If X does not Granger-cause Y, then X does not help in predicting Y. If both variables exhibit Granger causality toward each other, a bidirectional feedback relationship exists. If neither variable Granger-causes the other, then the two variables are considered independent in terms of providing predictive information.

3. Scope and methodology

3.1. Taking the calculation of compensation for alteration of constructible land in Taichung City that was made nonconstructible in accordance with the city's spatial plan as an example

This study proposed a model based on the ROV method for appraisal of the compensation for alteration of privately owned constructible land. In this model, landowners ^[1] have

¹ The subject of compensation for alteration is the applicant (i.e., landowner) who applies to the central competent authority of the special municipality or county (city) as the landowner listed in the cadastral transcript at the

time. Therefore, the owner refers to the landowner listed in the cadastral transcript at the time when applying for the compensation for alteration.

complete ownership and decision-making power of the land before receiving compensation. Subsequently, the study employed real options theories for private landowners to determine the real options of the proposed model at the decision-making stage. In addition, the study examined a case of altered land and its valuation.

3.2. NPV at decision making stage of the compensation for the alteration of privately-owned constructible land

Conventionally, discounted cash flow analyses are used to value projects, companies, or assets, in which the time value of money is calculated at a discount rate. The sum of all discounted cash flows each year is the NPV, which can be calculated as follows:

$$NPV = \sum_{t=0}^n \frac{CI_t - CO_t}{(1+q)^t} \quad (1)$$

Here, t represents time (measured in years) and n represents the pricing date difference between the price of privately-owned constructible land before and after the alteration. As shown in Eq. (1), three crucial parameters exist for estimating the NPV of the land before and after the alteration, namely CI_t , CO_t , and q . In Eq. (1), NPV represents the compensation for alteration of the land. Therefore, the source of CI_t is the cash inflow (expressed as the price of constructible land before the alteration) of privately-owned constructible land in year t (during the application for compensation). Regarding CO_t , its source is the cash outflow (expressed as the price of the nonconstructible land) of privately-owned constructible land in year t (during the compensation application); and q is the discount rate.

The cash inflow of the land in year t (during the compensation application) can be calculated by the land area and the unit land price (unit land market price) of the constructible land before the spatial plan announcement of the special municipality or county (city) and pricing date adjustment. The market price of a unit of land it can be estimated by the supply, demand, and transaction status of the surrounding constructible land market; the pricing date adjustment can be calculated by the change in a price index such as the land price index (Shieh & Su, 2023) [48].

Regarding q , referring to Article 43 of the Regulations of Real Estate Appraisal, the discount rate should be based on whichever of the follow methods are the most comprehensive and appropriate: risk premium, market extraction, weighted average capital cost, debt coverage ratio, and effective gross income multiplier methods. In addition to the aforementioned methods, q can be calculated by several quantitative methods, including capital asset pricing model, multi-factor asset pricing model, and arbitrage pricing theory, or qualitatively designated by management according to the company's requirements or according to the threshold of a specific project (Mun, 2005) [40].

Regarding financial feasibility evaluation, both financial feasibility and balance mechanism must be considered. For financial feasibility, the following four conditions must be met: $NPV > 0$, internal rate of return $>$ weighted average capital cost, discounted payback period $>$ concession period, and self-liquidating ratio > 1 (Shieh & Su, 2023; Organization of Urban Re-s, 2015; Huang, 2019) [48, 43, 28].

3.3. ENPV at decision making stage of the compensation for the alteration of privately-owned constructible land

In the international literature on land development and public construction, there are three common options: a deferral option, an option to expand and an abandonment option (Chen *et al.*, 2004) [6]. As regards real options which are applicable to real estate development, they may be summarized as a deferral option, an abandonment option, an option to expand/ contract, a switching option, a growth option and a compound option (Trigeorgis, 2005; Guma, 2008) [54, 23].

Considering characters and management flexibilities of the proposed privately-owned social housing model, the private real estate developer generally has two real options at decision making stage, which are a deferral option and an abandonment option separately. As for the abandonment option, it is the last choice and will not be exercised in general conditions because of the irreversible investments, e.g. construction costs. So, the only considered real option is the deferral option (Shieh & Su, 2021; Li *et al.*, 2014) [47, 36].

According to Shieh & Su (2021) and Li *et al.* (2014) [47, 36], with the characteristics and management flexibility of the proposed model, a private individual (referred to as the landowner according to the Measures for Compensating Loss Incurred during The Implementation of Spatial Planning) generally have two real options in the decision-making stage, which are the deferral option and the abandonment option. Regarding abandonment, because it is irreversible, this is the least desirable option and will not be used under normal circumstances. In general, only the deferral option is considered.

According to Shieh & Su (2023) [48], the deferral option for privately-owned constructible land is an American option because after an individual obtains ownership of legally constructible land, they may apply in writing to the special municipality or county (city) for compensation for alteration from the day after the 1-year expiration the functional zone map was announced.

According to Shieh & Su (2023) [48], a variety of models and methods can be used to evaluate the option premium (OP), among which the Black-Scholes model is the most widely used due to its simplicity and accuracy. As mentioned, the deferral option is the primary real option for private landowners applying for compensation for alteration at the decision-making stage, and it shall be removed at any time from the day one year after the announcement of functional zone maps by the special municipality or county (city) competent authority. Because of the short period, the deferral option for private individuals to apply for compensation for alteration is simplified to European style. Therefore, the Black-Scholes model is suitable for the calculation. In addition, the basic model is modified by considering value leakage, which has various causes during the deferral period. With reference to Hui *et al.* (2011) [30], three assumptions are made before constructing the Black-Scholes model. (1) The compensation for privately-owned constructible land follows geometric Brownian motion, and its rate of return is normally distributed. (2) Throughout, the risk-free interest rate and land price fluctuations are known and remain constant. And, (3) the option is priced in a frictionless market. If the value leakage is δ , according to the stochastic differential equation, the value S_t at time t of the land before the alteration price S will change in the following form:

$$dS_t = (r_f - \delta)S_t dt + \sigma_s S_t dB_t \quad (2)$$

Here, r_f is the risk-free interest rate; σ_s is the average volatility of prices for privately-owned constructible land; and B_t is one-dimensional Brownian motion. On the basis of the risk-neutral hypothesis and Itô's lemma (Chen, 2007), the stochastic differential equation of the privately-owned constructible land's OP and its boundary condition can be written as:

$$\frac{\partial OP}{\partial t} = r_f OP - (r_f - \delta)S_t \frac{\partial OP}{\partial t} - \frac{1}{2}\sigma_s^2 S_t^2 \frac{\partial^2 OP}{\partial S_t^2} \quad (3-1)$$

$$OP(S_t, T) = \text{Max}[(S_t - C_t), 0] \quad (3-2)$$

Here, C_t is the price at which the privately-owned constructible land is made nonconstructible in year t . Solve the stochastic differential equations of Eqs. (3-1) and (3-2) as follows:

$$OP_t = S_t e^{-\delta(T-t)} N(d_1) - C_t e^{-r_f(T-t)} N(d_2) \quad (4-1)$$

$$d_1 = \frac{\ln(S_t/C_t) + (r_f - \delta + \sigma_s^2/2)t}{\sigma_s \sqrt{T-t}} \quad (4-2)$$

$$d_2 = \frac{\ln(S_t/C_t) - (r_f - \delta + \sigma_s^2/2)t}{\sigma_s \sqrt{T-t}} = d_1 - \sigma_s \sqrt{T-t} \quad (4-3)$$

Here, T is the expiration date of the deferral option for compensation for alteration of privately-owned constructible land; and $N(d_1)$ and $N(d_2)$ are the cumulative probability of variables smaller than d_1 and d_2 under standard normal distribution, respectively.

According to Shieh & Su (2023) [48], the conventional NPV method has been repeatedly criticized for its disabilities in dealing with uncertainty, irreversibility and management flexibility, while these disabilities can be cured by ROV. However, as a broadly utilized decision making approach, the NPV method has many undeniable advantages (Chen, 2007) [5]. Trigeorgis (2005) [54] put forward a new expanded NPV criterion to capture the additional value of managerial operating flexibility and other strategic interactions: Expanded (or strategic) NPV (ENPV) = passive NPV + Option Premium (OP) (ROV, Flexibility value and Strategic value).

In such a model, there may be legitimate reasons for accepting negative NPV under expected cash flow (if the expected cash flow is offset by a larger OP generated by the additional flexibility and strategic value) or to delay an investment with positive NPV until the ENPV is maximized under uncertainty (Shieh & Su, 2021; Trigeorgis, 2005) [47, 54].

This study adopted, optimized, and illustrated the model to appraise the compensation for alteration of privately-owned constructible land.

The study calculated the value of the compensation at the decision-making stage. When Eqs. (4-1) to (4-3) are combined with Eq (1), t becomes 0, and the ROV model at the decision-making stage can be written as

$$ENPV = \sum_{t=0}^n \frac{(C_t - CO_t)}{(1+i_c)^t} + S_0 e^{-\delta T} N(d_1) - C_0 e^{-r_f T} N(d_2) \quad (5-1)$$

$$d_1 = \frac{\ln(S_0/C_0) + (r_f - \delta + \sigma_s^2/2)T}{\sigma_s \sqrt{T}} \quad (5-2)$$

$$d_2 = \frac{\ln(S_0/C_0) - (r_f - \delta + \sigma_s^2/2)T}{\sigma_s \sqrt{T}} = d_1 - \sigma_s \sqrt{T} \quad (5-3)$$

3.4. The test content according to the Granger causality test

3.4.1. Taiwan Economic Policy Uncertainty Index

In this study, the variable for Economic policy uncertainty (EPU) is derived from the Taiwan EPU Index constructed by Huang *et al.* (2021) [29], which follows the methodology of Baker *et al.* (2014, 2016) [1, 2] and EPU indices developed for other countries. The data source consists of online news articles from major newspapers spanning from May 1, 2003, to June 30, 2018. The sample period for the Taiwan EPU Index used in this study covers January 2004 to December 2017 (a total of 168 months, or 14 years), with monthly frequency.

In addition, "compensation for alteration" are based on the evaluation of land prices, and the relevant index is the land price index. The land eligible for applying for compensation for alteration is non-urban land; however, there is currently no officially published non-urban land price index in Taiwan. Since this study selects Taichung City as the empirical study area, it ultimately adopts the Taichung City Land Price Index from the Urban Land Price Index, which is periodically published by the Ministry of the Interior, as the subject of analysis.

After aligning with the sample period of the Taiwan EPU index mentioned above, the sample period for the Taichung City Land Price Index in this study spans from March 31, 2004 (22nd period) to September 30, 2017 (49th period), totaling 28 periods (14 years) with a semiannual frequency.

3.4.2. The definition of Variable

When examining whether economic policy uncertainty has a significant impact on compensation for alteration, this study takes the natural logarithm of the Urban Land Price Index in period t (Urban Land Price Index _{t}) and denotes it as the land price index ($\ln LP_t$).

Thus,

$$\ln LP_t = \ln(\text{Urban Land Price Index})_t \quad (6-1)$$

Following the approaches of Shieh & Su (2026), Su (2023) and Li (2022), this study obtains the EPU indices for five Asian economies—China, Hong Kong, Japan, South Korea,

and Singapore—from the website established by Baker *et al.* (2016). It then examines the impact of economic policy uncertainty on housing prices in each country. The EPU index of country i in period $t-1$ (EPU_{t-1}^i) is transformed by taking its natural logarithm to serve as the variable measuring economic policy uncertainty for each country ($\ln EPU_{t-1}^i$). Thus, $\ln EPU_{t-1}^i = \ln(\text{Country EPU Index of Period } t-1) =$

$$\ln(EPU_{t-1}^i) \quad (6-2)$$

When examining whether economic policy uncertainty has a significant impact on the amount of compensation for alteration, this study takes the natural logarithm of the Taiwan EPU index in period $t-1$ ($TEPU_{t-1}$) as the variable measuring Taiwan's economic policy uncertainty ($\ln TEPU_{t-1}$).

Thus, $\ln TEPU_{t-1} = \ln(\text{Taiwan EPU Index of Period } t-1) =$

$$\ln(TEPU_{t-1}^i) \quad (6-3)$$

3.4.3. Analysis steps

The data defined in the aforementioned variables are time series data. Following the approaches of Shieh & Su (2026), Su (2023), Li (2022), Chen (2013), and, Liu (2008), this study sequentially employs unit root tests, cointegration tests, and Granger causality tests for analysis. These methods are used to examine whether there exist leading and lagging relationships among the variables, as explained below.

3.4.3.1. Unit Root Test (This study adopts the ADF unit root test)

Time series data analysis generally involves two types of data characteristics: stationary and non-stationary series. If an external shock to a time series produces only a temporary effect that dissipates over time, allowing the series to return to its long-term mean level, then the probability distribution of the stochastic process does not change over time. In such cases, the mean, variance, and autocovariance are all finite constants, and the series is considered stationary.

In contrast, when a series is affected by an external shock that produces a persistent (permanent) impact, it exhibits a long-term memory characteristic, causing the data to gradually deviate from its mean. Such a series is referred to as a non-stationary time series and is characterized by the presence of a unit root.

If a time series must be differenced d times to achieve stationarity, it is called an “integrated of order d ” series, denoted as $I(d)$. If the series is already stationary without differencing, it is referred to as an “integrated of order zero” series, denoted as $I(0)$.

Methods for testing whether data are stationary originated from the Dickey-Fuller (DF) unit root test proposed by Fuller (1976) ^[19] and Dickey & Fuller (1979) ^[12], as well as the Augmented Dickey-Fuller (ADF) unit root test. The Augmented Dickey-Fuller (ADF) test proposed by Dickey & Fuller (1979) ^[12] extends the original Dickey-Fuller (DF) test by incorporating lagged terms of the dependent variable on the right-hand side of the regression equation, in order to account for the data-generating process of lagged time series and eliminate autocorrelation in the residuals. This study adopts the widely used ADF test to conduct unit root testing. Depending on whether the model includes an intercept term and a time trend term, the ADF unit root test can be classified

into the following three models:

3.4.3.1.1. No intercept and no time trend term

$$\Delta y_t = \beta y_{t-1} + \sum_{i=1}^n \gamma_i \Delta y_{t-i} + \varepsilon_t \quad (7-1)$$

3.4.3.1.2. With an intercept term but no time trend term

$$\Delta y_t = \alpha + \beta y_{t-1} + \sum_{i=1}^n \gamma_i \Delta y_{t-i} + \varepsilon_t \quad (7-2)$$

3.4.3.1.3. With an intercept term and a time trend term

$$\Delta y_t = \alpha + \beta y_{t-1} + \sum_{i=1}^n \gamma_i \Delta y_{t-i} + \delta t + \varepsilon_t \quad (7-3)$$

In Equations (7-1) to (7-3), Δ denotes the first difference, and y_t represents the index (variable) to be predicted. α is the intercept term, β is the autoregressive coefficient, and $\sum_{i=1}^n \gamma_i \Delta y_{t-i}$ represents the lagged terms of the dependent variable. Here, n is the optimal lag length that ensures ε_t follows white noise, δt represents the time trend, and ε_t is the error term, which is assumed to satisfy the white noise condition.

The hypotheses for the above three models are as follows:

$$H_0 : \beta = 0 \text{ (unit root exists)} \quad (8-1)$$

$$H_0 : \beta \neq 0 \text{ (no unit root)} \quad (8-2)$$

If the original series fails to reject the null hypothesis $H_0: \beta=0$ (i.e., a unit root exists), it can be concluded that the series contains a unit root. In such a case, the series should be differenced repeatedly until it becomes stationary.

To correct for autocorrelation in the residuals and ensure that they follow a white noise process, appropriate adjustments are required. According to Yang (2009) ^[57], white noise refers to a time series of random variables that satisfies specific statistical properties: a mean of zero, a constant variance, and zero autocovariance. If a time series meets these conditions, it is considered a white noise process.

When conducting the ADF test, it is necessary to determine the optimal lag length. If the selected lag length is too long, it may lead to inefficient estimation; if it is too short, important information may be omitted, resulting in biased estimates. This study adopts the Akaike Information Criterion (AIC), proposed by Japanese statistician Hirotoshi Akaike in 1969, to determine the optimal lag length. The lag length corresponding to the minimum AIC value is considered optimal. Referring to Yang (2009) ^[57], the formula is defined as follows:

$$AIC = T \ln SSE + 2k \quad (8-3)$$

Here, T is the total sample size, SSE is the sum of squared errors (in natural logarithmic form), and k is the total number of parameters to be estimated.

3.4.3.2. Cointegration Test

According to Chen (2013) ^[8], citing Engle & Granger (1987) ^[16], cointegration refers to a situation in which a set of non-stationary time series variables has a stationary linear combination; in this case, these variables are said to exhibit a cointegration relationship. There are two main approaches to cointegration testing: the two-step cointegration test

proposed by Engle & Granger (1987)^[16], and the multivariate cointegration test proposed by Johansen (1988)^[33].

The two-step method is applicable only when there is a single cointegrating vector among the variables. However, in practice, there may be multiple cointegrating vectors, and the two-step method does not provide an appropriate statistical measure to determine the number of such vectors. Therefore, empirical studies commonly adopt the Johansen cointegration test. The Johansen approach is based on the Vector Autoregression (VAR) model proposed by Sims (1980)^[50] and incorporates the corresponding error correction mechanism.

Furthermore, according to Chen (2013)^[8], citing Engle & Granger (1987)^[16], if a group of time series variables is cointegrated, there must exist a corresponding error correction model (ECM). Through the ECM, one can fully understand both the short-term dynamic relationships among the variables and the process by which short-term disequilibrium adjusts toward long-term equilibrium. When the Johansen cointegration test indicates the existence of a cointegration relationship among variables, the lagged error correction term representing the long-term relationship should be incorporated into the VAR model, forming a Vector Error Correction Model (VECM). Thus, the variables are influenced not only by their own past values and those of other variables but also by the previous period's disequilibrium.

A VAR model consists of a system of multiple variables and multiple regression equations. In each equation, the dependent variable is expressed as a function of its own lagged values as well as the lagged values of other variables. A general VAR model can be represented as follows:

$$Y_t = A_0 + \sum_{i=1}^z A_i Y_{t-i} + \varepsilon_{yt} \quad (9-1)$$

Here, Y_{t-i} is an $(n \times 1)$ vector representing a jointly covariance stationary linear stochastic process. A_0 is an $(n \times 1)$ intercept vector, A_i is an $(n \times n)$ coefficient matrix, and Y_{t-i} is an $(n \times 1)$ vector of lagged values of Y_t . ε_{yt} represents the structural disturbance term, which is an $(n \times 1)$ vector composed of the disturbances associated with the lagged terms of Y_t , and it is assumed to follow a white noise process.

In addition, the error correction model (ECM) established by Engle & Granger (1987)^[16] can be expressed as follows:

$$\Delta Y_t = \alpha_1 + \alpha_y e_{t-1} + \sum_{i=1}^z a_i \Delta Y_{t-i} + \sum_{i=1}^z b_i \Delta X_{t-i} + \varepsilon_{yt} \quad (9-2)$$

$$\Delta X_t = \alpha_2 + \alpha_x e_{t-1} + \sum_{i=1}^z c_i \Delta Y_{t-i} + \sum_{i=1}^z d_i \Delta X_{t-i} + \varepsilon_{xt} \quad (9-3)$$

Here, e_{t-1} measures the degree of deviation from long-term equilibrium in period $t-1$, i.e., the error correction term. α_y and α_x are the error correction coefficients, α_1 and α_2 are intercept terms, and z represents the optimal lag length. ε_{yt} and ε_{xt} are both white noise, while a_i , b_i , c_i , and d_i denote short-term dynamic adjustment coefficients, which indicate whether short-term relationships exist among the variables.

Referring to Shieh & Su (2026)^[49] and Su (2023)^[48], this study first employs the ADF unit root test to preliminarily examine the data characteristics. If the variables are

stationary, a Vector Autoregression (VAR) model is directly used for estimation and analysis. If the variables contain a unit root $I(d)$ (i.e., are non-stationary) and have different orders, belonging to $I(0)$ or $I(1)$ (order less than 2), the Autoregressive Distributed Lag (ARDL) model developed by Pesaran, Shin & Smith (2001)^[45] is applied.

If the variables contain a unit root $I(d)$ and include orders up to $I(2)$, the ARDL model is not applicable, as it only supports $I(0)$ and $I(1)$ variables and may lead to biased inference when applied to $I(2)$ data (Nkoro & Uko, 2016)^[42]. In such cases, following Yang (2015)^[56], this study adopts the more flexible Johansen cointegration test to examine cointegration relationships, and then applies the Vector Error Correction Model (VECM) to analyze short-term dynamics. If no cointegration relationship exists, it indicates the absence of a long-term relationship among variables. In this situation, non-stationary variables are differenced and analyzed using a VAR model, with the optimal lag length determined by the Akaike Information Criterion (AIC).

If the variables are all $I(1)$, the Johansen cointegration test is used to determine whether a long-term equilibrium relationship exists. If cointegration is present, a VECM is estimated; if not, the variables are first differenced and analyzed using a VAR model, again with lag length determined by AIC.

Furthermore, even when variables have different integration orders (less than 2), cointegration may still exist after appropriate differencing to achieve a common order. In such cases, the Johansen cointegration test can be applied after transforming the data to the same integration order.

When variables are $I(0)$ and $I(1)$, this study uses the ARDL model to examine whether economic policy uncertainty has a significant impact on social housing rents. According to Li (2022)^[37], the ARDL model has three main advantages: (1) it allows for simultaneous analysis of both long-term and short-term relationships; (2) it is suitable for studies with small sample sizes; and (3) it accommodates variables of different integration orders ($I(0)$ and $I(1)$), thereby addressing issues of inconsistent data orders.

According to Shieh & Su (2026), Su (2023) and Li (2022)^[49, 48, 37], the ARDL model developed by Pesaran *et al.* (2001)^[45] allows not only the inclusion of lagged dependent variables but also contemporaneous and lagged independent variables in the regression framework. It does not require all variables to be $I(1)$; as long as they are $I(0)$ or $I(1)$, the model can be applied. Moreover, it resolves issues of differing integration orders while providing consistent estimates of both long-term equilibrium relationships and short-term dynamics, making it particularly suitable for small-sample studies.

Following Su (2023)^[48], the ARDL(p, q) model established by Pesaran *et al.* (2001) is specified as follows:

$$\Delta \ln LP_t = \alpha_0 + \sum_{i=0}^p \beta_i \Delta \ln LP_{t-i} + \sum_{i=0}^q \gamma_i \Delta \ln TEPU_{t-i} + \delta_i \ln LP_{t-1} + \tau_i \ln TEPU_{t-1} + \varepsilon_t \quad (10-1)$$

In Equation (10-1), $\Delta \ln LP_{t-i}$ represents the change in the natural logarithm of the Taichung City Land Price Index for period $t-i$, and $\Delta \ln TEPU_{t-i}$ represents the change in the natural logarithm of the Taiwan EPU index for period $t-i$. ε_t is the error term. $\ln LP_t$ denotes the natural logarithm of the land price index in period t , while $\ln TEPU_{t-1}$ denotes the natural logarithm of the Taiwan

EPU index in period $t-1$.

In Equation (10-1), p represents the lag length of the land price index (after taking the natural logarithm), and q represents the lag length of the Taiwan EPU index (after taking the natural logarithm). α_0 denotes the intercept term. In the ARDL(p, q) model constructed in this study, p and q represent the lag lengths of the dependent and independent variables, respectively. These lag lengths are selected based on the Akaike Information Criterion (AIC), choosing the optimal lag length that minimizes the AIC value.

According to Su (2023) [48] and Li (2022) [37], after establishing the ARDL model, the Bounds Test proposed by Pesaran *et al.* (2001) [45] is applied to determine whether a long-term relationship exists between the dependent and independent variables. In this study, the Bounds Test is used to examine whether a long-term cointegration relationship exists between the land price index and the Taiwan EPU index. Following Pesaran *et al.* (2001) [45], the null hypothesis is specified as follows:

$$H_0 : \delta = \tau = 0 \text{ (no cointegration)} \quad (10-2)$$

Here, δ and τ represent the estimated long-term coefficients of the dependent and independent variables, respectively. If the estimated coefficients fail to reject H_0 , it indicates that there is no long-term cointegration relationship between the variables. Conversely, if the estimated coefficients reject H_0 , it implies that a long-term cointegration relationship exists between the variables.

This study determines the results based on the F-statistic and the critical value bounds provided by Pesaran *et al.* (2001) [45]. In this framework, the lower bound corresponds to $I(0)$, and the upper bound corresponds to $I(1)$. If the F-statistic is less than $I(0)$, H_0 cannot be rejected, indicating no long-term cointegration relationship. If the F-statistic exceeds $I(1)$, H_0 is rejected, indicating the existence of a long-term cointegration relationship. If the F-statistic falls between $I(0)$ and $I(1)$, the result is inconclusive.

If the test result shows that the F-statistic is greater than $I(1)$, it indicates that a long-term cointegration relationship exists between the land price index and the Taiwan EPU index. In this case, further analysis can be conducted to examine the impact of Taiwan's economic policy uncertainty on the land price index.

3.4.3.3. Granger Causality Test

According to Shieh & Su (2026) [49], Su (2023) [48], Li (2022) [37], Lin (2013) [38], and Liu (2008) [39], Granger causality was proposed by Granger (1969) [21]. It decomposes the relationships among variables into multiple independent regression equations, incorporating both the lagged terms of the dependent variable itself and the lagged terms of explanatory variables. Through this test, one can identify the lead or lag relationships between two variables. The Granger causality model is based on a predictive perspective, examining the "correlation" between the current value of one

variable and the past values of other variables.

In order to examine the lead-lag relationship between the compensation for alteration and economic policy uncertainty, this study establishes the following regression model:

$$\ln LP_t = \alpha_0 + \sum_{i=1}^k \beta_{1i} \ln LP_{t-i} + \sum_{i=1}^k \delta_{1i} \ln TEPU_{t-i} + \varepsilon_{1i} \quad (11-1)$$

$$\ln TEPU_t = \alpha_1 + \sum_{i=1}^k \beta_{2i} \ln TEPU_{t-i} + \sum_{i=1}^k \delta_{2i} \ln LP_{t-i} + \varepsilon_{2i} \quad (11-2)$$

According to Li (2022) [37], when $\delta_{1i} \neq 0$ and $\delta_{2i} = 0$, it indicates that $\ln LP_t$ Granger-causes $\ln TEPU_t$, representing a unidirectional causal relationship. When $\delta_{1i} = 0$ and $\delta_{2i} \neq 0$, it indicates that $\ln TEPU_t$ Granger-causes $\ln LP_t$, also representing a unidirectional causal relationship.

When $\delta_{1i} \neq 0$ and $\delta_{2i} \neq 0$, it indicates that $\ln LP_t$ and $\ln TEPU_t$ Granger-causes each other, representing a bidirectional causal relationship. When $\delta_{1i} = 0$ and $\delta_{2i} = 0$, it indicates that there is no causal relationship between $\ln LP_t$ and $\ln TEPU_t$.

4. Case study

4.1. Basic information

According to Su (2023) and Shieh & Su (2023) [48], to illustrate the application of the real option in the model, this study used a case in which constructible land in Taichung City was made nonconstructible by the city's spatial plan. The main index related to constructible land was taken from the Taichung City Spatial Planning Technical Report published on the website of the Construction and Planning Agency of the Ministry of the Interior.

The land was located on Shenghe Road, Taiping District, Taichung City, which was a Type C construction land. It was a non-disaster-type environmentally sensitive area measuring 153.38 m². On April 30, 2021, the administrative district announced its spatial plan, and the unit land price at the time of the announcement was estimated by this study to be NT\$15,000 per m² (i.e., the price of the constructible land before the alteration was NT\$15,000 per m²). The landowners can apply for compensation for the alteration on July 1, 2026. The unit land price at the time of the application for compensation was estimated by this study to be NT\$5000 per m² (i.e., the price is NT\$5000 per m² after the constructible land was altered). The land designated as nonconstructible is 153.38 m², and the scope of land ownership rights included was "all" (1/1). According to the valuation of this study, if the time point (April 30, 2021) of the announcement of the spatial plan was used as the benchmark to the time point of application for compensation (July 1, 2026), the reasonable land price increase rate for the surrounding Type C constructible land is 10%. Table 3 presents the main indices used in the study.

Table 3: Main indices of privately-owned constructible land

Name	Value	Name	Value
Land area before alteration (10 ⁴ m ²)	0.015338	Area of land designated as nonconstructible (10 ⁴ m ²)	0.015338
Unit land price at the time of the spatial plan announcement (NT\$/m ²)	15,000	Unit land price when applying for compensation (NT\$/m ²)	5,000
Pricing date adjustment rate (%)	10	Scope of land ownership rights	1/1

4.2. Model parameters

4.2.1. Parameters related to net present value

According to the proposed valuation model, certain parameters should be predetermined to calculate the NPV of the compensation, including CI_t , CO_t , and q . In accordance with the calculation formula in Article 11 of the Measures for Compensating Loss Incurred during The Implementation of Spatial Planning and after adjusting prices and dates, this study obtained the calculation results for relevant parameters, as follows:

CI_t = Unit land price at time of spatial plan announcement adjusted to unit land price at the time of compensation application \times land area designated as nonconstructible \times scope of land ownership rights

$$= (\text{NT}\$15,000/\text{m}^2 \times (1 + 10\%)) \times 153.38 \text{ m}^2 \times (1/1) \\ = \text{NT}\$2,530,770$$

CO_t = Unit land price at time of compensation application \times land area designated as nonconstructible \times scope of land ownership rights

$$= (\text{NT}\$5,000/\text{m}^2) \times 153.38 \text{ m}^2 \times (1/1) \\ = \text{NT}\$766,900$$

$q = 2.26\%$ (Calculated in accordance with Article 43 of the Regulations on Real Estate Appraisal, which is estimated as 2.26% by this study).

4.2.2. Real option-related parameters

According to Su (2023) and Shieh & Su (2023) ^[48], to calculate the OP in Eqs. (5-1) to (5-3), six parameter values were required. The first parameter was maturity time T . After ownership of constructible land was obtained, the deferral option of an application for compensation for alteration (American option) could be exercised at any time from 1 year after the competent authority publishes the functional zone maps. With reference to the surrounding land price changes, T was estimated to be 1 year. To be precise, when appraising the compensation, the 1-year deferral option was considered. The second parameter was the current value of S_0 , which was the discounted value at the decision-making stage. It could estimate the unit land price of the land at the time of the announcement based on q (3.26%) and the pricing date adjustment rate (estimated as 10%). According to the aforementioned parameters, S_0 was calculated as NT\$2,530,770.

The third parameter was the investment cost C_0 . In this case, it referred to the price of privately-owned constructible land made nonconstructible at the time of the application for compensation. It was also the discounted value at the decision-making stage, which can be estimated based on q and irreversible investment. According to the aforementioned parameters, C_0 can be calculated as NT\$766,900.

The fourth parameter was value leakage δ . According to data availability, only δ caused by the increase in cost is considered. The C_0 of this case was calculated based on the price change at the time of the compensation application. Moreover, this study used the period during compensation application as the basis for price calculation, and the unit land price of the land at the time of the announcement was adjusted to the price. The price fluctuation of the nonconstructible land did not need to be considered when applying for compensation. Therefore, the δ of the compensation for alteration is calculated as 0%.

The fifth parameter was the risk-free interest rate r_f , which was generally based on the rate of return on government debt (Chen, 2007) ^[5]. On November 8, 2019, the Central Bank of the Republic of China sold a 30-year treasury bond with an annual interest rate of 0.95%. This was used for the calculation of r_f . Therefore, in this study, the r_f of the renewed land and buildings related to the discount to offset the common cost was 0.95%.

The sixth parameter was the average volatility of the price of privately-owned constructible land σ_s . This study calculated σ_s as 2.00% (10%/5 years).

5. Results and discussions

5.1. Valuation model results

Input the aforementioned parameters of the compensation for alteration relative to the NPV into Eq. (1), and the NPV of the compensation for privately-owned constructible land in this case was calculated as NT\$1.58 million, which was positive. Subsequently, OP-related parameters were substituted into Eqs. (5-2) and (5-3) to obtain d_1 and d_2 , producing 1.68 and 0.71, respectively. In addition, $N(d_1)$ and $N(d_2)$ were obtained from the standard normal distribution function table as 0.9292 and 0.8212, respectively. Next, $N(d_1)$ and $N(d_2)$ and other OP-related parameters were substituted into Eq. (5-1) to obtain the OP value, which was NT\$1.73 million. Finally, NPV and OP were added together to obtain the ENPV of the compensation, which was NT\$3.31 million. In Table 4, an overview of the OP-related parameters and their values is provided.

Table 4: Overview of OP-related parameters and their values

Variable	Symbol	Description	Value
OP-related parameters	T	The maturity time	1 year
	S ₀	The current value	2.53 million NTD
	C ₀	The investment cost	0.77million NTD
	δ	The value leakage of the discounted price of the land and buildings	0.00%
	r _f	The risk-free interest rate	0.95%
	σ _s	The average volatility of SH rent	2.00%
	d ₁	$\frac{[\ln(S_0/C_0) + (r_f - \delta + \sigma^2/2)]}{\sigma\sqrt{T}}$	1.68
	d ₂	$\frac{[\ln(S_0/C_0) - (r_f - \delta + \sigma^2/2)]}{\sigma\sqrt{T}}$	0.71
	N(d ₁)	Cumulative probability of less than d ₁ variable under standard normal distribution	0.9292
	N(d ₂)	Cumulative probability of less than d ₂ variable under standard normal distribution	0.8212
	OP	Option premium, $S_0e^{-\delta T}N(d_1) - C_0e^{-rT}N(d_2)$	1.73 million NTD
	ENPV	Expanded net present value of the land and buildings after the renewal of the common cost is offset by the discount	3.31 million NTD

Therefore, this case was acceptable financially if the OP generated from the 1-year deferral option was considered. In general, compared with immediate application on the day after the special municipality or county (city) competent authority announces functional zone maps after the expiration date of 1 year, private landowners should wait an additional year after the expiration date before applying for compensation for alteration (Su, 2023; Shieh & Su, 2023) [48]. However, the private landowner in this case may be dissatisfied with the ENPV of the compensation for alteration and be eager to learn of methods to enhance ENPV. When this occurs, sensitivity analyses can be performed to determine possible influencing factors.

Regarding the case in this study, this study identified three factors potentially influencing ENPV. For earnings, these were calculated based on the price before the alteration of the land by the spatial plan. The unit land price at the time of the announcement was the most influential, hence, it was a potential factor. Regarding cost, it was calculated based on the price change of the land, which would have fluctuated over time. However, cost in this case was generated only during the compensation application. Moreover, this study used the time when compensation was applied for as the basis for price calculation, and the unit land price of the land at the

time of the announcement was adjusted to the price at that time. Therefore, the price fluctuation of the land during the application did not need to be considered, and the unit land price during the application was a potential factor (Su, 2023; Shieh & Su, 2023) [48].

Another potential factor was the area of constructible land designated as nonconstructible, which will affect both cost and earnings. Among the OP-related parameters, both S₀ and C₀ were affected by NPV-related parameters, whereas δ, r_f, and S were not under private control in this case. Therefore, T (in the OP-related parameters) was also a potential factor. This was because after obtaining ownership of the constructible land, the private landowner in this case can defer the compensation for alteration from 1 year after the competent authority publishes the functional zone maps (Su, 2023; Shieh & Su, 2023) [48].

The calculations indicated the effect of these three potential influencing factors on the ENPV of the compensation. The sensitivity analysis is shown in Figure 1. Apparently, the unit land price at the time of the plan announcement is the most crucial factor affecting its ENPV. The second most crucial factor was the area of constructible land made nonconstructible. Regarding T, its effect was minor and could be ignored (Su, 2023; Shieh & Su, 2023) [48].

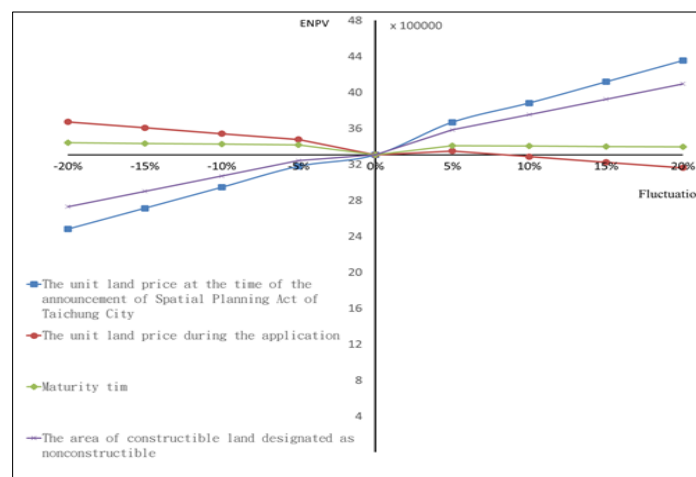


Fig 1: Sensitivity analysis results

5.2. Examining the impact of economic policy uncertainty on the unit land price used in calculating compensation for alteration at the time of application—based on the Granger causality test

5.2.1. Description of the research sample

The sample period for the Taichung City Land Price Index (LP) spans from March 31, 2004, to September 30, 2017. The sample collection dates include March 31, 2004, September 30, 2004, ..., March 31, 2017, and September 30, 2017, with a total of 28 observations and a semiannual frequency. The sample period for the Taiwan EPU index (TEPU) spans from April 1, 2004, to October 1, 2017. The sample collection dates include April 1, 2004, October 1, 2004, ..., April 1, 2017, and October 1, 2017, with a total of 28 observations and a semiannual frequency.

5.2.2. Descriptive statistics of the research sample data

Table 5 presents the descriptive statistics of the sample data related to compensation for alteration in this study, including the descriptive statistics of the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU). As shown in Table 5, there are a total of 28 observations during the sample

period. The variable LP represents the Taichung City Land Price Index, while TEPU represents the Taiwan Economic Policy Uncertainty index. This study uses EViews statistical software as the analytical tool.

According to Table 5, both LP and TEPU exhibit positive skewness. The Taichung City Land Price Index (LP) shows a platykurtic distribution, while the Taiwan EPU index (TEPU) exhibits a leptokurtic distribution. The Jarque–Bera test results indicate that the p-value for LP is greater than 0.1, suggesting that the null hypothesis of normal distribution cannot be rejected. In contrast, the p-value for TEPU is 0, leading to the rejection of the null hypothesis that the series follows a normal distribution.

As noted in Table 5, following Su (2023) [48], Chen (2013) [8], and Hsu (2011) [27], the J-B value refers to the Jarque–Bera statistic, which is used to test whether a time series follows a normal distribution. The null hypothesis states that the tested variable is normally distributed. Given that a normal distribution has a skewness of 0 and a kurtosis of 3, if the series deviates from these characteristics, the null hypothesis of normality is rejected.

Table 5: Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU)

Variable	Mean	Standard deviation	Minimal value	Median	Maximal value	Skewness	Kurtosis	J-B value	P-value	Sample size
LP	96.0054	14.6364	79.52	87.77	118.58	0.5735	1.5912	3.8505	0.1458	28
TEPU	121.8661	72.8188	52.24	122.245	422.45	2.8311	11.8849	129.5024	0.0000	28

Regarding the trend charts of the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU), they are shown in Figures 2 and 3, respectively. The trend of the Taichung City Land Price Index (LP) shows a long-term upward pattern, with two mild declining periods. In contrast, the Taiwan EPU index (TEPU) exhibits a long-term pattern of repeated fluctuations, along with a sharp increase. This

sharp rise is mainly attributed to major events related to economic uncertainty—such as presidential recall cases and the global financial crisis—which are closely associated with the Taiwan EPU index (with values exceeding 100). In particular, during the global financial crisis, Taiwan experienced the highest level of economic policy uncertainty.

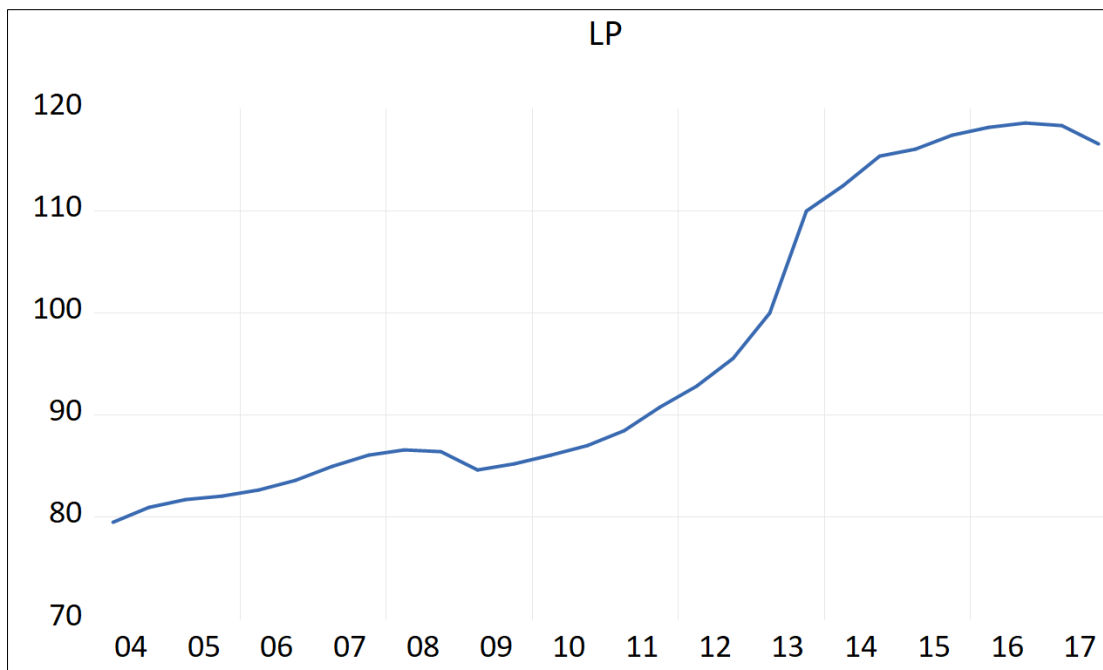


Fig 2: Trend of the Taichung City Land Price Index (LP)

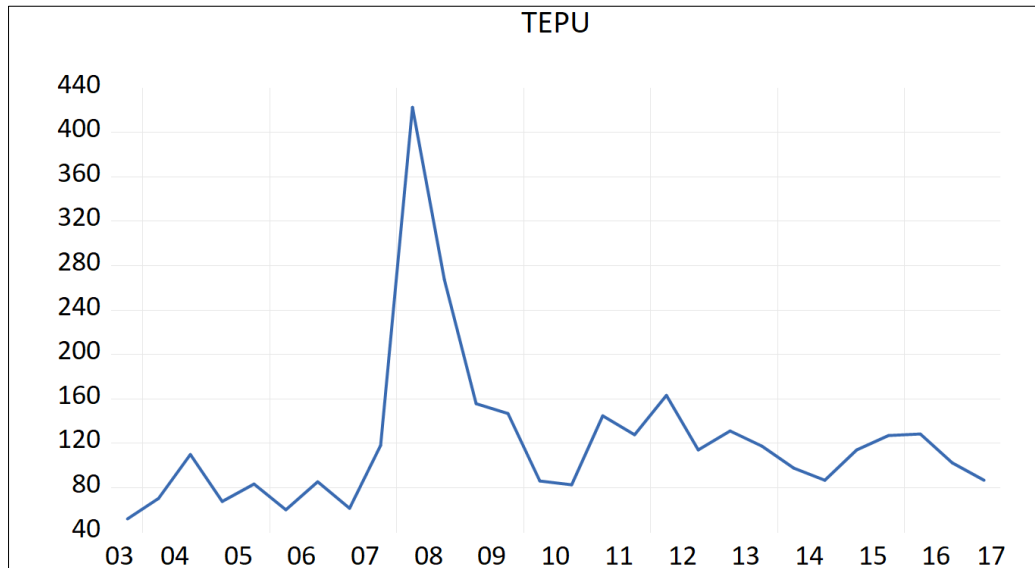


Fig 3: Trend of the Taiwan EPU Index (TEPU)

The distribution charts of the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU) are shown in Figures 4 and 5, respectively. The distribution of the Taichung City Land Price Index (LP) is non-normal, showing a left-skewed

pattern with a portion distributed on the right side as well. Similarly, the distribution of the Taiwan EPU index (TEPU) is also non-normal, with the distribution range skewed to the left.

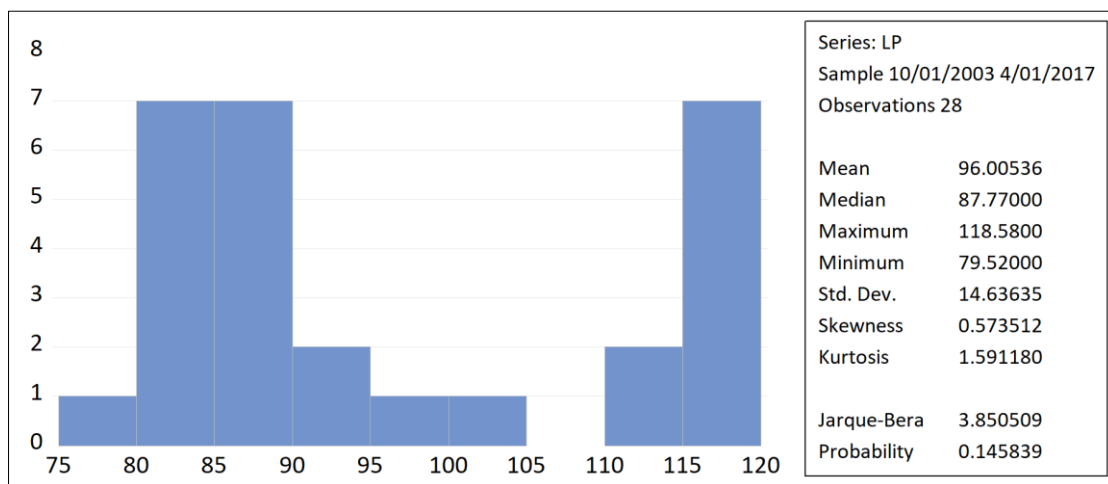


Fig 4: Distribution of the Taichung City Land Price Index (LP)

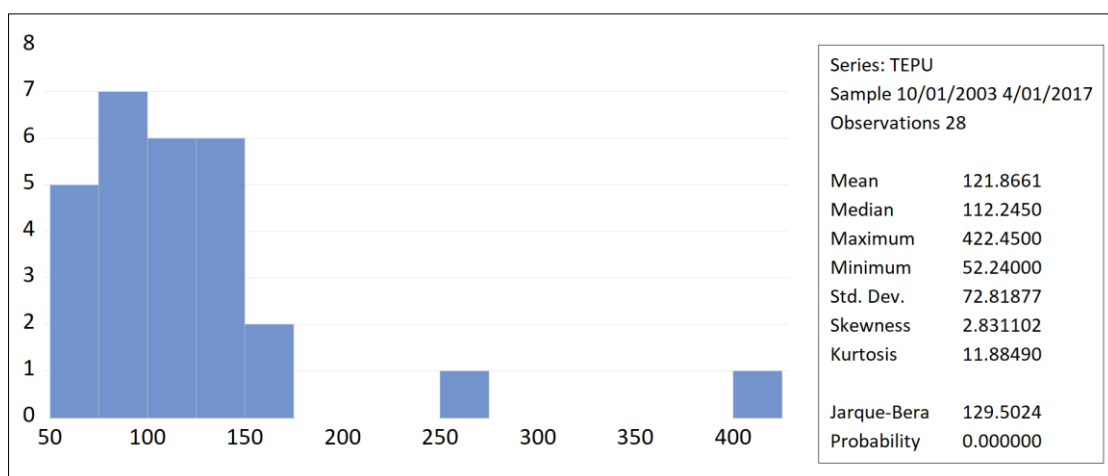


Fig 5: Distribution of the Taiwan EPU Index (TEPU)

5.2.3. Correlation analysis of the research sample

Table 6 presents the correlation analysis between the natural logarithms of the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU). As shown in Table 6, the original data of the natural logarithm of the Taichung City Land Price Index (ln LP) and the natural logarithm of the Taiwan EPU index (ln TEPU) exhibit a positive relationship. This indicates that higher economic policy uncertainty in Taiwan tends to drive up land prices.

According to previous literature, the relationship between economic policy uncertainty and land prices, housing prices, and rents may be either positive or negative across different countries. Therefore, examining the impact of economic policy uncertainty on land prices, housing prices, and rents helps us understand how these variables respond when economic policy uncertainty arises, and such analysis carries meaningful implications.

Table 6: Summary of the correlation analysis between the natural logarithms of the Taichung City Land Price Index (LP) and the Taiwan EPU Index (TEPU)

Variable	ln LP	ln TEPU
ln LP	1	0.1016
ln TEPU	0.1016	1

Table 7: Summary of ADF unit root test results for ln LP and ln TEPU based on original data

Model	Model with intercept but no time trend (Intersept)		Model with intercept and time trend (Trend and Intersept)	
Variable	t-Statistic	P-Value	t-Statistic	P-Value
ln LP	-0.6958	0.8309	-2.0663	0.5395
ln TEPU	-3.0307**	0.0446	-2.8295	0.1996

Note: *** indicates rejection of the null hypothesis at the 1% significance level; ** indicates rejection at the 5% significance level; * indicates rejection at the 10% significance level. The null hypothesis is rejected when the absolute value of the t-statistic is equal to or greater than the absolute value of the critical value.

Under the model with an intercept but no time trend, the critical values for the ADF test based on the original data are -3.7115, -2.9810, and -2.6299 for ln LP at the 1%, 5%, and 10% significance levels, respectively, and -3.6999, -2.9763, and -2.6274 for ln TEPU. Under the model with both an intercept and a time trend, the corresponding critical values are -4.3561, -3.5950, and -3.2335 for ln LP, and -4.3393, -3.5875, and -3.2292 for ln TEPU at the 1%, 5%, and 10% significance levels.

At the 1% significance level, both ln LP and ln TEPU based on the original data fail to reject the null hypothesis, indicating that all variables are non-stationary.

Since the unit root tests based on the original data indicate that all series are non-stationary, differencing is required until the series become stationary before further analysis can be conducted.

After taking the natural logarithm of the Taichung City Land Price Index (ln LP) and applying first differencing, under

5.2.4. Unit root test of the research sample

Table 7 presents the results of the ADF unit root test for the natural logarithms of the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU).

For the original data of the natural logarithm of the Taichung City Land Price Index (ln LP), under both the model with an intercept but no time trend (Intersept) and the model with both an intercept and a time trend (Trend and Intersept), at the 1% significance level, all p-values are greater than 0.01 and the absolute values of the t-statistics are smaller than the corresponding critical values. Therefore, the null hypothesis cannot be rejected, indicating that the data are non-stationary and contain a unit root. As a result, first differencing is required until the series becomes stationary before further analysis can be conducted.

Similarly, for the original data of the natural logarithm of the Taiwan EPU index (ln TEPU), under both model specifications, at the 1% significance level, all p-values are greater than 0.01 and the absolute values of the t-statistics are smaller than the critical values. Thus, the null hypothesis cannot be rejected, indicating that the data are also non-stationary and contain a unit root. Therefore, differencing is required until the series becomes stationary before proceeding with further analysis.

both the model with an intercept but no time trend (Intersept) and the model with both an intercept and a time trend (Trend and Intersept), at the 1% significance level, all p-values are greater than 0.01 and the absolute values of the t-statistics are smaller than the corresponding critical values. Therefore, the null hypothesis cannot be rejected, indicating that the series remains non-stationary and still contains a unit root. As a result, second differencing is required until the series becomes stationary before proceeding with further analysis.

In contrast, after taking the natural logarithm of the Taiwan EPU index (ln TEPU) and applying first differencing, under both model specifications, at the 1% significance level, all p-values are less than 0.01 and the absolute values of the t-statistics are equal to or greater than the critical values. Thus, the null hypothesis can be rejected, indicating that the data are stationary and do not contain a unit root. Details are shown in Table 8.

Table 8: Summary of ADF unit root test results for ln LP and ln TEPU based on first differencing

Model	Model with intercept but no time trend (Intersept)		Model with intercept and time trend (Trend and Intersept)	
Variable	t-Statistic	P-Value	t-Statistic	P-Value
ln LP	-2.4948	0.1282	-2.3950	0.3733
ln TEPU	-5.3138***	0.0002	-5.2885***	0.0012

Note: *** indicates rejection of the null hypothesis at the 1% significance level; ** indicates rejection at the 5% significance level; * indicates rejection at the 10% significance level. The null hypothesis is rejected when the absolute value of the t-statistic is equal to or greater than the absolute value of the critical value.

Under the model with an intercept but no time trend, the critical values for the ADF test of ln LP and ln TEPU (based on first differencing) at the 1%, 5%, and 10% significance levels are -3.7115, -2.9810, and -2.6299, respectively. Under the model with both an intercept and a time trend, the corresponding critical values are -4.3561, -3.5950, and -3.2335.

For ln LP, all first-differenced values fail to reject the null hypothesis, indicating that the variable remains non-stationary. In contrast, for ln TEPU, all first-differenced values reject the null hypothesis, indicating that the variable

is stationary.

After taking the natural logarithm of the Taichung City Land Price Index (ln LP) and applying second differencing, under both the model with an intercept but no time trend (Intercept) and the model with both an intercept and a time trend (Trend and Intercept), at the 1% significance level, all p-values are less than 0.01 and the absolute values of the t-statistics are equal to or greater than the corresponding critical values. Therefore, the null hypothesis can be rejected in all cases, indicating that the data are stationary and do not contain a unit root. Details are shown in Table 9.

Table 9: Summary of ADF unit root test results for ln LP based on second differencing

Model	Model with intercept but no time trend (Intersept)		Model with intercept and time trend (Trend and Intersept)	
	t-Statistic	P-Value	t-Statistic	P-Value
ln LP	-2.4948	0.1282	-2.3950	0.3733

Note: *** indicates rejection of the null hypothesis at the 1% significance level; ** indicates rejection at the 5% significance level; * indicates rejection at the 10% significance level. The null hypothesis is rejected when the absolute value of the t-statistic is equal to or greater than the absolute value of the critical value.

Under the model with an intercept but no time trend, the critical values for the ADF test of ln LP (based on second differencing) at the 1%, 5%, and 10% significance levels are -3.7241, -2.9862, and -2.6326, respectively. Under the model with both an intercept and a time trend, the corresponding critical values are -4.3743, -3.6032, and -3.2381.

For ln LP, all second-differenced values reject the null hypothesis, indicating that the variable is stationary.

5.2.5. Bounds test for cointegration of the research sample

According to the ADF unit root test results in Tables 7, 8, and 9, the natural logarithm of the Taichung City Land Price Index (ln LP) and the natural logarithm of the Taiwan EPU index (ln TEPU) exhibit inconsistent orders of integration (ln TEPU is I(1), while ln LP is I(2)). Based on the previously discussed methodology for the Granger causality test, when variables contain unit roots with different orders and include I(2), the Autoregressive Distributed Lag (ARDL) model is not applicable, as it is only suitable for variables of order I(0)

and I(1), and applying it to I(2) data may lead to biased inference.

In such cases, this study adopts the more flexible Johansen cointegration test to examine the existence of a cointegration relationship and uses the Vector Error Correction Model (VECM) to analyze short-term dynamics. If no cointegration relationship exists, it indicates the absence of a long-term relationship among the variables. Under this condition, the non-stationary variables are differenced and analyzed using a Vector Autoregression (VAR) model to examine the relationships among variables, with the optimal lag length determined by the Akaike Information Criterion (AIC).

The results of the Johansen cointegration test are shown in Table 10. For the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU), at the 5% significance level, the Trace Statistic and Max-Eigen Statistic are 9.8860 and 8.7568, respectively, both of which are smaller than the critical values. This indicates that the null hypothesis of no cointegration cannot be rejected. In other words, there is no long-term cointegration relationship between LP and TEPU.

Table 10: Cointegration test between the Taichung City Land Price Index (LP) and the Taiwan EPU Index (TEPU)

Hypothesized	Trace	0.05	P-Value	Max-Eigen	0.05	P-Value
No. of CE(s)	Statistic	Critical Value		Statistic	Critical Value	
None	9.8860	15.4947	0.2896	8.7568	14.2646	0.3070
At most 1	1.1292	3.8415	0.2879	1.1292	3.8415	0.2879

Table 11 summarizes the cointegration coefficients. From an economic perspective, the signs of the coefficients indicate the direction of the relationship between the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU) (Enders, 2004). Specifically, in the long run, a 1% increase in land prices leads to a 0.09% decrease in the Taiwan EPU index (TEPU), while a 1% increase in the Taiwan EPU index (TEPU) leads to a 10.96% decrease in the Taichung City Land Price Index (LP).

Table 11: Cointegration coefficient table for the Taichung City Land Price Index (LP) and the Taiwan EPU Index (TEPU)

LP	TEPU
1.000000	-10.96267
	(3.67753)
LP	TEPU
-0.091219	1.000000
(0.92693)	

Based on the above analysis, this study finds that there is no long-term cointegration relationship between the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU). When no cointegration relationship exists between the variables, the non-stationary variables are differenced, and a Vector Autoregression (VAR) model is directly applied for analysis.

5.2.6. Vector Autoregression (VAR) model of the research sample

Following Su (2023), this study adopts the Akaike Information Criterion (AIC) to determine the optimal lag length. As shown in Table 12, the optimal lag length for the Taiwan EPU index (TEPU) is two periods.

Table 12: Optimal lag length of the Taiwan EPU Index (TEPU)

LP and TEPU		
Lag length	LR	AIC
0	NA	0.006314
1	74.33795	-3.542573
2	10.58690*	-3.801695*
3	1.186157	-3.517136
4	1.384627	-3.260009
5	0.773722	-2.966711
6	1.275123	-2.744755

5.2.7. Granger Causality Test

The results of the Granger causality test between the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU) are shown in Table 13. The results indicate that there is no causal relationship between LP and TEPU.

Table 13: Summary of the Granger causality test between the Taichung City Land Price Index (LP) and the Taiwan EPU Index (TEPU)

Null Hypothesis	F-statistic	P-Value
LP does not Granger	2.0081	0.1592
TEPU does not	0.0141	0.9861

Note: *** indicates rejection of the null hypothesis at the 1% significance level; ** indicates rejection at the 5% significance level; * indicates rejection at the 10% significance level. Based on the p-values, both null hypotheses—"LP does not Granger-cause TEPU" and "TEPU does not Granger-cause LP"—cannot be rejected. Therefore, there is no causal relationship between LP and TEPU.

6. Conclusions

To protect the rights of landholders, the Ministry of the Interior has established the Measures for Compensating Loss Incurred during The Implementation of Spatial Planning under the authorization of Article 32, Paragraph 3 of the Spatial Planning Act, which provides for compensation for relocation and alteration. Compensation for alteration refers to compensation for losses suffered when constructible land is made nonconstructible in the spatial planning of the special municipality or county (city). It is to compensate for the value of the development rights of the land (reflected in the difference in unit land prices before and after the spatial planning). The appraisal method is different from the current method of market price of land expropriation and compensation.

Thus, land must be assessed for compensation for alteration.

However, the appraisal method differs from the current

method of market price for land expropriation and compensation. This study proposed a new calculation model of compensation for alteration of privately-owned constructible land. According to the management flexibility of the model at the decision-making stage, the study considered only the deferral option. Subsequently, the study established an ROV model in which the expanded (or strategic) NPV was represented by ENPV, was equal to the sum of the NPV and the OP.

The study also took the case of constructible land in Taichung City made nonconstructible in accordance with the city's spatial plan as an example to illustrate the valuation model. However, because the OP generated from the 1-year deferral option was positive, the compensation for alteration in this case shall be applied 1 year after the expiration date of the functional zone maps announced by the competent authority. According to the sensitivity analysis of the compensation for alteration valuation model proposed in this study, the unit land price at the time of the spatial plan announcement was the factor with the greatest effect on the ENPV. The primary factor influencing this unit land price is σ_s (the average volatility of prices for privately-owned constructible land). Therefore, when calculating compensation for alteration, accurately determining the future trend of σ_s is a key factor affecting the compensation amount.

In this study, σ_s is assumed to be 2.00%, which is positive (>0). However, in practice, σ_s is not necessarily always positive, as it is often influenced by changes in economic policy. In such cases, further judgment can be made based on the results of the Granger causality test between land prices and the economic policy uncertainty index. According to the results of this study, there is no causal relationship between the Taichung City Land Price Index (LP) and the Taiwan EPU index (TEPU).

According to Chen & Tseng (2008)^[7], the absence of herding behavior in land price indices may be due to the fact that land price data are not purely market-based, and land prices are often influenced by government policies. Other possible reasons include insufficient data length, sample periods coinciding with economic downturns, or reduced land investment activity. According to Hsieh (2020)^[25], the implementation of the integrated housing and land tax has no significant effect on land price volatility, which is consistent with the findings of this study. Furthermore, Lai (2002)^[34] suggests that when analyzing the structure of land prices, it is insufficient to consider only direct influencing factors; "economic structural factors" must also be incorporated. For example, Taiwan experienced significant land price fluctuations around 1988 due to structural economic changes. Taking Taichung City as an example, since there is no causal relationship between LP and TEPU, changes in the Taiwan EPU index alone cannot be used as the basis for determining the future trend of σ_s when calculating the option premium (OP). In such cases, the future trend of σ_s should be assessed by incorporating "economic structural factors" into the analysis of land price determinants.

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